Development of a Tool Management System for Energy Sector Company

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Abstract

As the world of business continues to change rapidly and dramatically, organisations are also subjected to continuous changes. Starting from 21st century, the concept of a global market place is influencing the manufacturing organisations throughout the world in contrasting ways. However with the product life cycles becoming shorter, inventory management is becoming as dicey as to predict one's future. Moreover owing to the uncertainties in demand of products, managing inventory levels is becoming highly complex and hence crucial to a company's survival. Since fewer mathematical models have been used to manage inventories, an attempt has been made to apply models to manage inventories in the tool warehouse.

In the study, 10% reduction in the total supply chain cost through the development of a tool management system has been targeted. Inventory related data has been collected from April 2011 to October 2011. After analysing the demand patterns, tools have been classified into certain and uncertain demand category of products. Under certain demand, EOQ Model, complete aggregation model and tailored aggregation model has been used for low, medium and high valued products respectively. On the contrary, uncertain demand products have been modelled using safety stock and cycle service levels. Finally comparative analysis has been carried out between legacy and used models in terms of total supply chain cost.

Results revealed 7% savings from the EOQ model for low value products; 21% savings from aggregation model for medium value products; 18% savings from tailored aggregation method for high value products and 23% savings from probability model for products with uncertain demand. In addition, most frequently used carbide inserts have been aggregated and corresponding optimal order frequency and lot sizes have been arrived. Further, the study can be carried out for other categories of products in the selected energy sector company.

Key Words: EOQ, Complete Aggregation Method, Tailored Aggregation Method, Cycle Service Level

1. INTRODUCTION

The world of business continues to change rapidly and dramatically. Business organisations are under constant pressure to reinvent and reorganise themselves continually in order to meet demands of the global market place. When it comes to manufacturing industry, the scenario is more intricate due to the complexities of the sundry activities involved. A manufacturing organisation can be viewed as a system which transforms raw materials into finished products through the use of manufacturing resources. The manufacturing resources are crucial aspects in this process and can be considered to be anything that is required to produce the final product. As a manufacturing resource, tooling is a fundamental aspect of this transformation process, and it is an inescapable fact of manufacturing life that every manufactured product is built using a tool or by a machine that was made using tools.

In a traditional manufacturing environment, dedicated machinery handled dedicated tooling and a limited number of tools have been associated with each machine on the shop floor and operators monitored, maintained, and replenished these in liaison with stores personnel who managed the tooling resources with the aid of card/index system. Advances in manufacturing technology such as Machining Cell and Flexible manufacturing system also required the direct supply of tools from a local tool storage area.

However, increasing versatility of NC and CNC machines, and a corresponding increase in work diversity, has resulted in increasing number of tools being associated with individual machines. As a result, the operators have no longer been sufficiently in control to accept the responsibility for management of tooling. Further, the availability of correct tooling in the right condition has been vital to continuous flow of production in any manufacturing environment. Given these factors, it has been imperative that management and control of tooling resources should receive far more attention. Mathematical inventory modeling has been now considered the way forward for managing tooling resources.

1.1 Study Execution

The area allotted for study execution has been tool warehouse where all the cutting tools and accessories necessary for performing all the machining operations required to manufacture all the products have been stored. The tools used have been broadly classified into two – 'consumables and non consumables' based on their consumption pattern.

1.2 Products under Study

There have been lots of varieties of tools stored in the tool warehouse. The most critical one identified has been carbide inserts as shown in Figure 1 of various sizes and geometries used for specific machining applications. The other items shown in include drills for producing round holes, taps for making threads, end mills and milling cutters for material removal application and adaptors used for clamping the above mentioned tools onto the machine.

Fig. 1 Carbide inserts

1.3 Rationale for Selecting the Topic for Study

The main problems identified after consultation with the concerned tooling-in-charge have been high tool inventory and consequently high inventory cost. Presently there has been no proper system to monitor the inventory levels, re-ordering strategies and also the costs associated with procurement of tools and accessories. This emphasized the need for having a dedicated tool management system that could help the concerned people associated with the tooling to decide on what products to be ordered at what time in what quantities so that the total cost as well as the inventory levels has been optimized. The current demand pattern for the tools being used has been studied using a pilot data collection and the same has been applied in developing specific mathematical models for the tool management system. The attempt of developing a tool management system as the sole aim of this study also focuses on reducing the total cost without compromising on the product availability.

2. PROBLEM DEFINATION

The main problems identified in the tool warehouse operations have been tool unavailability, high inventory and discrepancies in the re-ordering of tools. These problems have been directly contributing to the high cost associated with the tool ware house operations. Thus a need for a scientific mathematical inventory models for optimising the inventory, re-ordering frequencies and also to reduce the total annual costs has been identified

2.1 Aim

To develop a Tool Management System (TMS) to reduce the total supply chain cost by 10 %

2.2 Objectives of the Study

- To review the literature on various tool management and inventory management systems in supply chain
- To understand and collect data of the existing process in the tool warehouse
- To analyse the flow of tools based on the demand pattern, optimum ordering quantity and frequency
- To develop a suitable Tool Management System (TMS) to suit the above mentioned requirements
- To validate and recommend TMS using pilot data (Apr 2011-Oct 2011) to arrive at optimum ordering frequencies

2.3 Methods and Methodology Used

- Literature review for tool management and inventory management systems has been carried out by referring journals, books, manuals and related documents
- Existing process has been studied using a process mapping procedure
- Data has been collected using company documents and observations
- Demand pattern of the tools has been analyzed using current ordering quantity, re-ordering frequency and inventory levels
- TMS model has been developed using
- EOQ model for low valued products
- Aggregation method for medium valued products
- Tailored aggregation method for high valued products
- Safety inventory for products with uncertain demand using probability concepts
- The TMS has been validated and recommended based on the results obtained from the past data

3. SOLUTION PROCEDURE

The analysis of the collected data has been done and it has been understood that the specific mathematical inventory models have to be developed for specific product categories based on demand pattern followed by those products. This detailed step by step procedure of modeling of various inventory models and also their illustration has been explained below.

3.1 Selection of Inventory Models

Many organizations make use of mathematical inventory models to maximize their profit. The various inventory models assist in determining the optimal times to procure or order products and also advise the quantity of product that must be procured in order to keep the total supply chain costs down.

Situations	Demand	Lead time	Type of Model to be adopted
1	Constant	Constant	Deterministic Model
2	Constant	Variable	Probabilistic Model
3	Variable	Constant	Probabilistic Model
4	Variable	Variable	Probabilistic Model

Table 1. Criteria for selecting inventory model

Table 1 shows the criterion for selecting a particular inventory model for different situations based on how demand and lead time for a particular product varies over a particular time span. From the analysis of the data collected, it has been understood that the two different situations applicable to the existing scenario has been 1 and 3. After having a discussion with the tool warehouse in charge, it has been decided that deterministic models have been used for situation 1 where the demand and lead time for procurement has been fairly stable and probabilistic model for situation 3 where the demand has been variable and lead time for procurement has been constant.

The various mathematical inventory models that have been applied for a group of selected products after analysis and discussion have been summarised as follows.

Deterministic Model

- EOQ model for low valued products
- Aggregation method for medium valued products
- Tailored aggregation method for high valued products

Probabilistic Model

- Safety inventory for products with uncertain demand

3.2 Developing Deterministic Inventory Models

For doing the different deterministic inventory models the following inputs have been assumed

'D' = Annual demand of the product

'S' = Fixed cost incurred per order

's' = Product - specific fixed cost

'C' = Cost per unit

'h' = Holding cost as a fraction of product cost (20% assumed)

3.2.1 Economic Order Quantity (EOQ) Model

EOQ model has been applied for low cost products to find out the order quantity that minimizes total inventory, ordering costs and holding costs. In this study, EOQ model has been applied for a group of products known as "Fasteners" which have been commonly used for mechanically joining or fixing two or more objects together.

Steps involved in developing EOQ model

The lot sizing decision to minimize the total cost has been made by considering the following individual costs

- Annual Material Cost
- Annual Ordering Cost
- Annual Holding Cost

Since purchase price has been independent of lot size,

1. Annual Material Cost = CxD ……..... **(1)**
2. The number of orders must suffice to meet the annual demand *D*. Given a lot size of *Q*

Therefore number of orders per year = $\frac{D}{Q}$ ……...... **(2)**

An order cost of *S* has been incurred for each order placed,

3. Annual Order Cost = $\left(\frac{D}{Q^*}\right)S$ ……..... **(3)**

Given a lot size of *Q*, the average inventory accounts to *Q*/2. Thus the annual holding cost has been the cost of holding *Q*/2 units in inventory for one year (six months in this particular case).

4. Annual Holding Cost = $\left(\frac{Q^*}{2}\right)H = \left(\frac{Q^*}{2}\right)hC$ .... **(4)**
5. Thus the Total Annual Cost,

$$TC = CxD + \left(\frac{D}{Q^*}\right)S + \left(\frac{Q^*}{2}\right)hC \quad \text{…..... (5)}$$

Optimal lot size is the one that minimizes the total cost and it has been found by taking the first derivative of the total cost with respective to *Q* and setting it equal it to 0. The optimal lot is size has been referred to as the *Economic Order Quantity (EOQ).*

6. Optimal lot size, $Q^* = \sqrt{\frac{2DS}{hC}}$ ……..... **(6)**
7. The optimal ordering frequency is given by

$$n^* = \frac{D}{Q^*} = \sqrt{\frac{DhC}{2S}} \quad \text{……..... (7)}$$

3.2.2 Complete Aggregation Model

Aggregating replenishments across products or suppliers in a single order helps to reduce lot size for individual products because fixed ordering and transportation costs have been spread across multiple products or suppliers. The objective of this model has been to arrive at lot sizes and an ordering policy that minimize the total annual cost. The approach used under this model has been to jointly order different products. Since there have been nearly hundred varieties of carbide inserts being used in the machining department and developing an aggregation model for all of them being seemingly impossible, the most frequently used five insert types have been chosen.

Steps involved in developing Complete Aggregation Model:-

All the five products have been included each time an order has been placed. Therefore the combined fixed order cost per order has been given by

$$S^* = S + \sum_{i=1}^{k} s_i \qquad \text{……... (8)}$$

Assuming '*n*' as the number of orders placed per year,

Annual Order Cost = $S^* n$ ……... **(9)**

Annual Holding Cost = $\sum_{i=1}^{k} \frac{DihCi}{2n^*}$ ……... **(10)**

The next step has been to identify the optimal ordering frequency. The optimal ordering frequency minimizes the total annual cost and has been obtained by taking the first derivative of the total cost with respect to '*n*' and setting it equal to 0. This has resulted in the optimal ordering frequency.

$$n^* = \sqrt{\frac{\sum_{i=1}^{k} D_i hC_i}{2S^*}} \qquad \text{……... (11)}$$

Total Annual Cost = $S^* n^* + \sum_{i=1}^{k} \frac{DihCi}{2n^*}$ …... **(12)**

3.2.3 Tailored Aggregation Model

The tailored aggregation model involves a more selective approach in combining products to be ordered jointly. An ordering policy with optimum cost has been developed by applying this model. The key to applying this model has been identifying the product that has to be ordered most frequently. The frequencies with which the other products have been ordered and included in subsequent orders have been decided. Since there have been numerous varieties of Taps being used in the machining department and developing a tailored aggregation model for all of them being apparently not viable, the most frequently used five Taps have been chosen.

Steps involved in developing Complete Aggregation Model

1. As a first step, the most frequently ordered product has been identified (Assuming each product has been ordered independently). In this case a fixed order cost of $S + s_i$ has been allocated to each product. The ordering frequency has been evaluated for each product selected for applying the model.

$$\bar{n} = \sqrt{\frac{hC_i D_i}{2(S + s_i)}} \qquad \text{……... (13)}$$

This has been the frequency at which each product would have been ordered if it has been the only product being ordered. Assuming $\bar{n}$ to be the frequency of the most frequently ordered product, this product has been included each time an order has been placed.

2. The frequency with which other products has been included with the most frequently ordered product; i.e. the order frequency for each product as a multiple of the order frequency of the most frequently ordered product has been identified. The most frequently ordered product has been ordered each time and all of the fixed cost *S* has thus been allocated to it. For each of the other products *i*, there has been only product-specific fixed cost. The ordering frequency for all other products has been calculated.

$$\bar{\bar{n}} = \sqrt{\frac{hC_i D_i}{2s_i}} \qquad \text{……... (14)}$$

3. The frequency of product *i* relative to the most frequently ordered product has been evaluated and fractional values have been rounded off to the closest integer.

$$\bar{m}_i = \frac{\bar{n}_i}{\bar{\bar{n}}_i} \qquad \text{……... (15)}$$

4. Having decided the ordering frequency of each product, the ordering frequency of the most frequently ordered product, *n* has been calculated.

$$n = \sqrt{\frac{\sum_{i=1}^{k} hC_i m_i D_i}{2(S + \sum \frac{s_i}{m_i})}} \qquad \text{……... (16)}$$

5. Optimum ordering frequency and order size for of each product has been evaluated

$$n_i = \frac{n}{m_i} \qquad \text{……... (17)}$$

$$Q = \frac{D}{n_i}$$

Finally the total annual cost has been calculated

TAC = Annual Holding Cost + Annual Order Cost

$$= \sum_{i=1}^{k} \frac{DihCi}{2n^*} + nS + \sum n_i s_i \qquad \text{…... (18)}$$

3.3 Developing Probabilistic Inventory Models

When the demand for a certain product has been uncertain there have been chances that a product shortage might occur if the actual demand exceeds the forecasted demand. In order to negotiate the negative effects of such a situation, an inventory named Safety Inventory has been carried to satisfy the demand that exceeds the amount forecasted for a given period. A replenishment policy consists of decisions regarding to when to reorder and how much to reorder. These decisions determine cycle and safety inventories along with fill rate and CSL (Cycle Service Level).

The following general assumptions have been made for developing the inventory models.

- The replenishment policy consists of a lot size *Q* ordered when the inventory on hand drops to the ROP
- It is assumed that the weekly demand has been normally distributed, with mean *D* and standard deviation σ_D

- A replenishment lead time of L weeks has also been assumed

3.3.1 Evaluating Safety Inventory given a Replenishment Policy

The method for evaluating safety inventory under continuous review policy has been mentioned below in consideration with the above stated assumptions regarding demand and replenishment lead time.

Expected demand during lead time, D_L = *DL* ..……. **(19)**

Assuming that a replenishment order is placed when ROP products are on hand,

Safety inventory, *ss* = *ROP* - *DL* ……..**. (20)**

3.3.2 Evaluating Cycle Service Level (CSL) given a Replenishment Policy

The procedure for evaluating CSL for continuous review policy has been discussed below. Given a replenishment policy the inventory model aims to evaluate the CSL, the probability of not stocking out in a replenishment cycle. A stock out occurs in a cycle if demand during lead time has been larger than the ROP.

Thus *CSL* = Prob (demand during lead time of L weeks $\leq ROP$) ……..**. (21)**

After taking into consideration the general assumptions, the probability has been evaluated as a function of the normal distribution.

$$CSL = F(ROP, D_{L,} \sigma_L) \quad \text{……... (22)}$$

3.3.3 Evaluating Safety Inventory given a Desired Cycle Service Level

In many practical settings, firms have desired level of product availability and want to design replenishment policies that achieve this level. The goal has been to obtain the appropriate level of safety inventory given the desired CSL. The general assumptions mentioned earlier stands true here also. Further the following inputs have been assumed.

1. Desired cycle service level = *CSL*
2. Mean Demand during lead time = *DL*
3. Std. deviation of demand during lead time = σ_L

As per Eq. no. **(20)** ROP = DL + *ss*

The safety inventory has been calculated such that the following equation is true

Prob (demand during lead time of L weeks $\leq$ DL + *ss*) = CSL

Given that demand has been normally distributed [(Eq. no. **(22)**], the safety inventory *ss* has to be identified such that the following has been true

$$F(D_L + ss, D_{L,} \sigma_L) = CSL \quad \text{……... (23)}$$

Therefore taking the inverse of the normal distribution,

$$D_L + ss = F^{-1}(CSL, D_{L,} \sigma_L)$$

Or

$$ss = F^{-1}(CSL, D_{L,} \sigma_L) - D_L \quad \text{……... (24)}$$

Using the definition of standard normal distribution and its inverse it can be shown that the following has been true.

$$ss = F_S^{-1}(CSL) \times \sigma_L \quad \text{……... (25)}$$

4. RESULTS AND DISCUSSIONS

The pilot data collection has been carried out for a period of 6 month period from April 2011 to October 2011 and the results obtained from the mathematical models have been compared against the existing legacy system being practiced in the company.

4.1 Results Obtained through EOQ Model for Fasteners

The *economic order quantity* model has been done for the low valued product category of "Fasteners." The optimal lot size (EOQ) and the optimal ordering frequency that could minimize the total annual cost for the selected products have been found out.

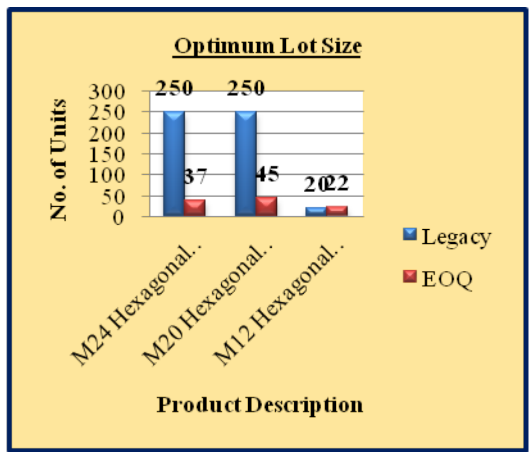

Fig.2 Comparison of ordering quantity

Figure. 2 shows the differences in ordering quantities of the three products between the existing legacy method and the proposed EOQ Model.

Figure 3 shows the comparison in the total annual cost of all the products selected for doing the EOQ Model. By analyzing the above bar graph it has been understood that 7% savings has been achieved after applying the EOQ Model. (Annual material cost has not been considered since it remains the same for both legacy system and the EOQ Model.)

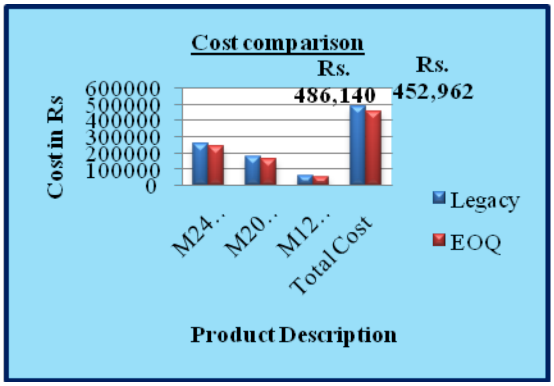

Fig. 3 Comparison of total annual cost

4.2 Results Obtained through Complete Aggregation Model for Carbide Inserts

The *Complete Aggregation* model has been done for the medium valued product category of "Carbide inserts." The optimal lot size and optimal ordering frequency that minimize the total annual cost for the selected products have been found out.

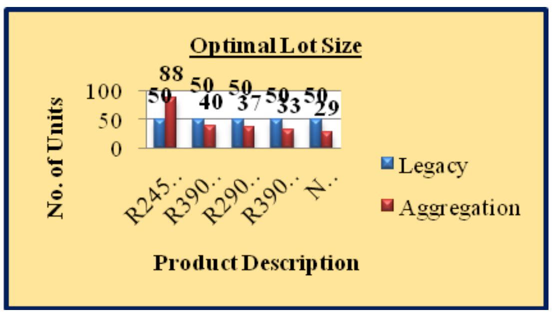

Fig. 4 Comparison of optimal lot size

Figure 4 shows the lot sizing followed under the legacy system and the changes happened to it after application of complete aggregation model

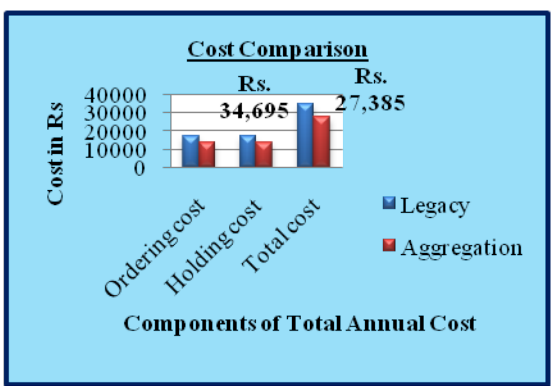

Fig. 5 Comparison of total annual cost

Figure 5 shows the comparison in the total annual cost of all the products selected for developing the Complete Aggregation Model. By analyzing the above bar graph it has been understood that **21% savings** over the existing legacy system have been achieved after applying the complete aggregation Model. (Annual material cost has not been considered since it remains the same for both the legacy system and the respective model.)

4.3 Results Obtained through Tailored Aggregation Model for Taps

The *Tailored Aggregation* model has been done for the high valued product category of "TAPS." The optimal lot size and optimal ordering frequency that minimise the total annual cost for the selected products have been found out.

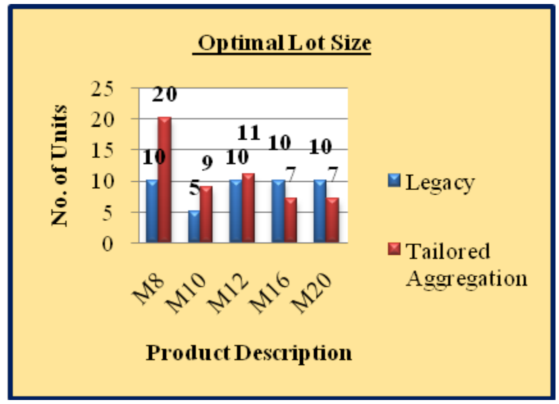

Fig. 6 Comparison of lot sizes

Figure 6 shows the lot sizing followed under the legacy system and the changes happened to it after the application of tailored aggregation model.

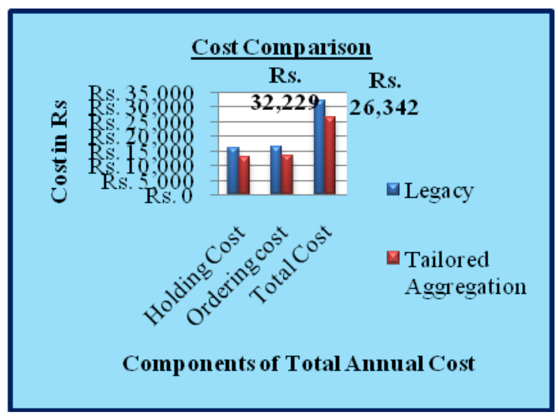

Fig. 7 Comparison of total annual cost

Figure 7 shows the comparison in the total annual cost of all the products selected for developing the Tailored Aggregation Model. By analyzing the above bar graph it has been understood that **18% savings** over the existing legacy system have been achieved after applying the tailored aggregation Model. (Annual material cost has not been considered since it remains the same for both the legacy system and the respective model.)

4.4 Results Obtained through Probability Model for Milling Cutters and End Mills

The *Probability* model has been done for the product category of "Milling cutters and end mills." The safety inventory to be maintained and the re-order point for an expected CSL of 80% that minimizes the total annual cost for the selected products have been found out.

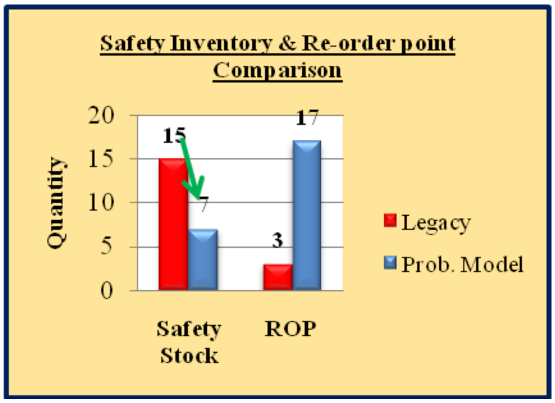

Fig. 8 Comparison of safety stock and re-order point

Figure 8 shows the comparison in the safety inventory maintained and the re-order point for the legacy system and the developed model.

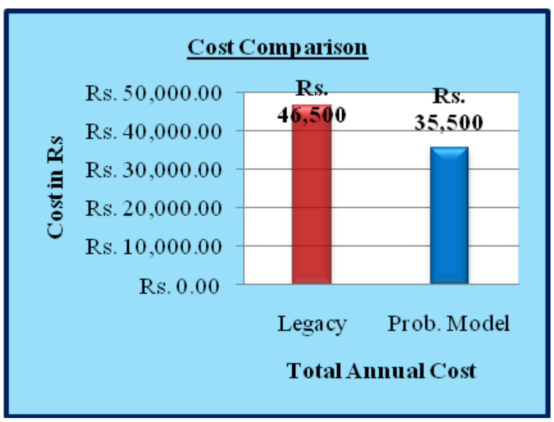

Fig 9 Comparison of total annual cost

Figure 9 shows the comparison in the total annual cost of the products selected for developing the probability model. By analyzing the above bar graph it has been understood that **23% savings** over the existing legacy system have been achieved after applying the developed model. (Annual material cost has not been considered since it remains the same for both the legacy system and the respective model.)

5. CONCLUSIONS

From the present study we found that the EOQ model applied to the product group of "Fasteners" resulted in a considerable reduction in the optimal lot size and also helped in reducing the total annual cost by 7%. The Complete Aggregation model has been applied to the product group of "Carbide Inserts". Five of the most frequently consumed inserts have been aggregated into a single order and this resulted in a reduction of 21% in the total annual cost. The inventory model for the product group of "TAPS" has been done using the tailored aggregation method and a 18% savings in the total annual cost have been achieved. The inventory model using the probability concepts has been applied to the product group of milling cutters and end mills. The safety stock and the cycle service level to be maintained has been found out and the model resulted in a 23% savings.

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